THE WORLD'S RESOURCES OF ENERGY

By R. BUCHERT

When we feel cold in winter and remember the summer heat, we may sometimes wonder why we do not store up the surplus heat of summer and consume it in the following winter. Or, likewise, why do we not use the cold of winter for cooling our rooms in summer, or the light of day for lighting our rooms at night?

Why it has not yet been possible to do such things and to what extent it may be possible in the future, depends on a series of problems which all relate to energy and which are discussed in the following pages. Dr. Buchert studied chemistry at German universities and has been living for the past few years in Japan.—K.M.

STORING UP ENERGY

WE generally use three forms of energy: energy of motion, a substitute and supplement for human labor in transporting men and objects; energy of heat, for providing warmth and for manufacturing goods the production of which is possible with high temperatures only; and energy of radiation, for lighting our rooms, for instance.

As shown by the questions above, the places and times of supply and the places and times of demand usually do not tally. In the tropics and in our summer there is a surplus of heat, whereas in the arctic regions and in our winter there is a deficiency of heat. The same unsatisfactory situation prevails with regard to motion and radiation. We see the waterfalls with their natural motion of water but cannot employ this motion directly for driving our cars, which need motion in other places than that of the waterfall. In order to obtain the right amount and kind of energy at the right place, we need means of storing, transporting, and transforming energy.

Mechanical energy, i.e., motion, can be stored in the form of water kept at high places, whence it can fall and thereby re-produce motion. The energy contained in the raised water is called potential energy, a fourth (auxiliary) form of energy. Clocks are likewise driven by raised weights. Similarly, wound-up springs release their energy when unwound, and compressed gases when expanded. These latter devices are transportable but possess only a very limited capacity for storing energy. On a large scale, mechanical energy can be stored only in the form of raised water, viz., in a nontransportable form.

It being almost impossible to store and transport heat and radiation, we must look for other, more convenient forms of energy. Thus for transporting energy we widely employ electricity, a fifth (auxiliary) form of energy, because it can be easily distributed to many distant places of consumption and easily transformed there into the required forms of energy: motion, heat, or radiation. But for the purpose of transporting energy, all points of consumption—whether our houses or electric streetcars—must be connected with the central source of electricity by means of conducting wires, for it is impossible to store electricity as such or move it freely. This makes it difficult to supply electricity to every consumer, especially to such movable consumers as motorcars or ships.

Fortunately, there is a sixth (auxiliary) form of energy: chemical energy. It is the energy contained in chemicals and released by them when they are decomposed. Contrary to the other forms of energy described, such decomposition can be carried out at any given place or time. Thus chemical energy represents the best form for storage and transport. As, however, chemicals—the carriers of this form of energy—possess weight, and the transport of heavy carriers consumes energy itself, it may happen that over long distances all the energy is consumed for the transport. Hence only those carriers which contain a lot of energy within a small weight are economical. The differences in capacity of some carriers are shown in the following table:

TABLE I

Chemical Carrier (1 kg.)	Chemical Process	Yield
Coal	Burning	12 hp-hours of heat
Gasoline	,,	16 ,, ,, ,, ,,
Dynamite	Exploding	2 ,, ,, ,, heat & motion
Accumulator	Discharging	0.04 hp-hours of electricity

We see that when weight has to be taken into account, as in motorcars and airplanes, gasoline is the best carrier of energy. We also see that, contrary to general belief, explosives do not contain vast quantities of energy. They are used, not because of the amount of energy they contain, but because of the velocity with which they deliver it, in other words, because of the energy they deliver in one second.

ENERGY FROM THE SUN

The energy used at present by mankind is derived almost without exception from the sun, which sends it to us in the form of radiation.

TABLE II

Estimate of Sun Power

Total power of the sun	500,000,000,000	billions of hp
Sun power received by the earth	200	,,
,, ,, absorbed ,, ,, atmosphere	80	,,
,, ,, ,, ,, ,, water surface	80	,,
,, ,, ,, ,, ,, land surface	40	,,
,, ,, received by 1 square meter of earth surface at a middle latitude		about 1 hp

TABLE III

Estimate of Some of the Earth's Energy Deposits

Clouds	4,400,000	billions of hp-hours
Coal	70,000	,, ,, ,, ,,
Wind	52,000	,, ,, ,, ,,
Vegetation ..	250	,, ,, ,, ,,
Petroleum ..	190	,, ,, ,, ,,

The enormous amount of energy which the earth receives from the sun in the form of radiation is transformed by nature and man in two ways: physically from radiation to heat and thence to motion and electricity; and chemically, from radiation to chemical energy and thence likewise to heat, motion, and electricity.

PHYSICAL TRANSFORMATION

The heat produced by the radiation of the sun is transformed physically. Heated gases rise owing to their decreased weight. Air warmed by the sun also rises, forcing colder air to flow into the vacuum thus formed. Wind is produced in this way and can be used by sailing ships and windmills. Though the energy content of the winds is very great, wind power engines are used only to a small extent as the inconstancy of the wind reduces the effectiveness of such engines. Moreover, there are only limited means of transforming wind motion into chemical energy; and where the windmills are situated there is usually no natural possibility of storing the energy in the form of raised water.

The evaporation of water produced by the sun's rays is also utilized. If pipes filled with water are arranged in the focus of lenses or concave mirrors, and the lenses or mirrors are exposed to the sun, the water evaporates and the steam may be used for moving engines. However, this process is restricted to regions of a sunny climate, and even there its use is limited by the inconstancy of sunshine.

For this reason it is more economical to use the natural evaporation of water. The energy carried by the rising moisture of rivers, lakes, and seas can be recovered as mechanical energy when the water falls again as rain. Where the rain falls onto elevated regions, a small portion (less than one per cent) of the energy of the rainfall is stored (as potential energy), and we concentrate it by means of dams. When this water falls to lower places, it delivers this small residue of the rain energy as water motion, turning mill wheels and turbogenerators for producing electricity.

CHEMICAL TRANSFORMATION

The radiation of the sun may also produce chemical substances which absorb the energy of the rays in the form of chemical energy. This process is carried out on a huge scale by the earth's vegetation. With the aid of sun energy, the plants transform the carbon dioxide of the atmosphere into carbon compounds. These carbon compounds (wood, coal, petroleum) release the energy stored in them when they are burned. Although this road from radiation to heat is already a long one, it is, nevertheless, sometimes economical further to lengthen it by converting the carbon compounds primarily produced by the sun into other, more convenient carbon compounds. For instance, coal is sometimes converted into artificial fuel oil, a liquid carrier of energy being more convenient to handle than a solid one like coal.

The heat produced by the combustion of carbon compounds is either used directly in our stoves or transformed by heat power engines—e.g., internal-combustion engines or steam engines—into mechanical energy. The mechanical energy thus produced is in turn either used directly as motion—for instance, for moving vehicles and other engines—or transformed by means of a dynamo into electricity. This electric energy may then easily be conducted to any desired place of use and transformed there into any desired form of energy, such as radiation (light, X-rays, or radio waves), heat, or motion.

SHORT CUTS

Both the physical as well as the chemical methods of transformation involve the turning of heat into motion. This step, however, yields only a small percentage of mechanical energy, as a great part of the heat used remains as heat. So it seems reasonable to try to avoid this step.

The direct transformation of radiation into motion without the production of heat would allow us to drive our cars with sunlight. Unfortunately, this transformation has so far only been possible with an infinitesimal yield. In a vacuum, the pressure of sun radiation is capable of moving small wheels; such radiometers or light mills are used to measure the intensity of a light beam. But any application of this phenomenon to practical use has so far been impossible.

If the direct production of electricity from radiation were possible, we could obtain all the electricity we wanted without any connection with a power plant, simply by using the sunshine on the roof of our house. But this transformation, too, is possible only on a tiny scale. The devices used in this process are photocells. In these photocells, the negative electric charges (electrons) of a plate are moved by radiation and produce an electric current when forced into a uniform direction by means of an electric field or by a layer which allows the electrons to pass only in one direction. Almost every photographer uses a photocell of this kind in the form of a photometer; but for any practical gain of electric energy they are, for the time being at least, too expensive to manufacture and yield too little energy. There are also photocells which transform radiation into chemical energy in a galvanic cell and release this energy when the cell is discharged.

The commonly known galvanic cells and accumulators represent devices for transforming chemical into electrical energy. As the metals producing the electric current are generally prepared with the aid of sun-produced coal, an accumulator actually converts sun radiation through chemical energy into electricity. However, for industrial production of electricity from sun energy it is inconvenient, being suitable only for the storage of comparatively small amounts of energy.

Far more useful would be devices which, instead of preparing metals first with the aid of coal and then obtaining an electric current from these metals, employed coal directly as the decomposing electrode of a galvanic cell. Since the present production of electricity from coal via heat and motion inevitably entails considerable losses, the construction of such fuel cells is an important problem facing science and industry. In a fuel cell, coal is decomposed, not by burning with the evolution of heat, but by oxidizing with the evolution of electricity, thus promising a more economical use of the energy contained in coal. Experiences have proved that such fuel cells are feasible; but so far their efficiency has not yet reached that of the ordinary coal power plants. In future times, however, they may become a serious competition to the present methods.

In nature, the direct transformation of chemical into mechanical energy without the detour via heat is effected by the muscles of the animal or human body. They transform the chemical energy contained in food into the motion of the limbs. But we are not yet able to imitate this natural process by technical means, except on a small scale. In fire extinguishers, the mixture of two chemicals produces a gas the pressure of which acts on the water contained in the extinguisher and forces it out in a jet. Devices of this kind are useful when it is necessary to start the transformation easily and swiftly and when it is a matter of avoiding high temperatures. But as far as capacity is concerned, they cannot compete with the combustion devices which transform chemical energy into motion via heat.

The direct transformation of heat into electricity without passing through the stage of motion is carried out by means of thermoelements. These consist of two kinds of metal wires whose ends are connected with each other, forming a circuit. If one end of the circuit is heated, the other being kept cool, a current is produced. Such devices are often used for measuring heat, especially high temperatures. The yield of electricity produced by such thermoelements is, however, too small to permit their use for the large-scale production of electricity.

ENERGY FROM OTHER SOURCES

The methods of obtaining energy explained above are possible only under certain natural conditions. The physical method requires water reservoirs; the chemical method, deposits of coal or petroleum. Without these deposited reserves, they are uneconomical. Moreover, the short cuts have not as yet yielded sufficient results. Hence we must now consider whether there are any other ways of obtaining energy.

The atmosphere of the earth always contains a certain electric charge varying according to the place and the distance from the surface of the earth. The difference in the charges of air layers of various heights is enormous, about 1,000 volts, for instance, between two layers ten meters apart. However, the quantities of electricity flowing between these layers are very small, so that the total amount of energy obtainable from this source is too slight for economical use.

A high electric power is contained in lightning, and it is already possible to overcome the technical difficulties of handling millions of volts discharged in a split second. The German scientists Brasch and Lange have used lightning as a source of high voltages. This method of gaining energy is, however, too inconstant and too uncertain for general use.

One might imagine it to be possible to make use of the rotation of the earth; but as yet we know of no means of harnessing this energy.

A somewhat easier problem is that of exploiting the tidal energy supplied to us by the moon. Tidal mills have been known since the Middle Ages. They consist of a basin which fills with sea water when the tide comes in and empties over mill wheels during ebb tide. Those in use are constructed for obtaining comparatively small amounts of energy only. Bigger power plants of a similar kind have been planned from time to time; they have, however, not yet been built on any large scale because of the high cost of construction, as enormous quantities of water have to flow through the turbines within a few hours at varying pressure, since the height of the water sometimes changes as much as three meters an hour.

One might also think of magnetism or of the earth's force of gravity as being sources of energy, but it must be remembered that these phenomena are not forms of energy but the properties of magnetic and gravitational fields. For that reason it is not possible to transform them into other forms of energy but only to transform one mechanical energy into another mechanical energy within such fields. In this way, for instance, the rise of moisture caused by the sun contrary to the direction of gravity needs more energy than a movement in other directions; this surplus of energy is stored (as potential energy) and released when the water falls again in the direction of gravity. Without the gravitational field, there would be no rise consuming energy and no fall releasing energy, but only movement.

Another source of heat is the heat contained within the earth. This heat appears at some places of the earth's surface in the form of hot springs. In Japan and Italy, hot springs are already being used for obtaining energy. Houses are heated directly with the hot water of the springs, and steam is produced by means of the heat of the springs, this steam moving turbogenerators which produce electric current. As these possibilities are limited to places possessing hot springs of a sufficient strength, it has been proposed that we try to produce artificial hot springs by boring deep pits and filling them with water. So far this has not yet been attempted. Other proposals to utilize the differences in temperature of the surfaces and the bottoms of tropical or arctic oceans have likewise not yet proved economical.

RAYS FROM THE COSMOS

In addition to the ordinary rays of the sun, the earth is also bombarded by cosmic rays. They are to be found everywhere, especially in the upper layers of the atmosphere, as has been proved by balloons sent into the stratosphere. We do not yet quite know where they come from, whether from the sun or from the galaxy, nor even to which kind of rays they belong. They represent a high concentration of energy: they penetrate lead plates two meters thick and are capable of disintegrating atoms and destroying life. These interesting rays cannot, however, be handled in any way; they cannot be artificially produced, nor can they even be deflected or concentrated.

A remarkable source of energy is to be found in the radioactive elements. To give one example: radium develops, until it is entirely decomposed, an energy 50,000 times as great as that produced by the same quantity of coal. The practical use of this source is, however, hindered by the fact that radioactive substances are available only in very small quantities, and that the energy contained in them cannot be obtained in a convenient form. Radium, for instance, takes no less than 1,750 years to release half of its great amount of energy. This means that its power, that is, the energy delivered in one second, is very small, much smaller than that of coal. On the other hand, there are other radioactive substances which discharge their energy with such extreme speed that half the substance is decomposed within a thousandth of a second. Science, observing these tremendous differences in velocity, is now trying to accelerate or retard them but has not succeeded in influencing the radioactivity in any way. Any practical use of the energy contained in radioactive substances can, therefore, only be expected if we are able to prepare radioactive substances artificially and then decompose them artificially to cause them to discharge their energy. Science is thus aiming at artificial atom disintegration instead of natural atom decomposition.

TINY BOMBSHELL OF ENERGY

The atom, the smallest unit of a chemical element we know, consists of a minute nucleus surrounded at a relatively large distance by one or several shells. If an atom were enlarged to the size of a house, the shells would be its walls but the nucleus only a grain of sand in its center. These shells consist of negative electric charges (electrons), the outer layers of which are responsible for the chemical qualities of the atom. As for the nucleus, we know nothing beyond its weight and its positive electric charge. Whoever intends to crush the nucleus has first to crush the electronic shells. The problem somewhat resembles that confronting a soldier who has to crush an iron-clad tower. He needs bullets of a suitable size and piercing power, and guns to fire such bullets. So we must investigate what bullets and what guns are available for crushing the nuclei.

As the bullets have to penetrate the electronic shells, they must possess a high speed. Furthermore, it is necessary to use the smallest possible particles as bullets, since a bullet should not be bigger than the target. Atoms, surrounded as they are by electronic shells, are too big for this purpose and are unable to move at a sufficient velocity. But atom nuclei, freed of their shells, are suitable bullets for artificial atom disintegration. Such nuclei are, for example, available as the fragments of natural radioactive decomposition. As a matter of fact, the first atom disintegration was carried out in 1919 with such fragments (alpha particles) as bullets and with the self-decomposing radium nucleus as the gun. Nuclei can also be obtained by removing the electronic shells of atoms by means of positive electricity. In this way, proton, the nucleus of the hydrogen atom, is produced.

For using proton or other artificial nuclei as bullets, complicated devices giving them a high speed are needed as guns. One of such devices is the cyclotron. It consists of two metal plates which are charged alternately, one positively and the other negatively and vice versa in rapid sequence. Attracted by these plates, a nucleus put between them begins to move to and fro like a pendulum. There is also a big magnet attached to this device, which deflects the nucleus from its straight path into a curved one, so that the nucleus moves in circles with increasing speed. When the speed is high enough, it leaves the device and is directed at the atom to be disintegrated.

The curious gun makes only one hit in a million shots. With this poor marksmanship it shoots invisibly small bullets at invisibly small targets: yet it is as big and heavy as a fully loaded railway carriage. Although this method may seem rather uneconomical, the device supplies us with a shooting power greater than that of all the radioactive material available put together. By thus bombarding nuclei, scientists have succeeded in disintegrating most of the atoms and in identifying their fragments. These fragments are often new, unknown atoms, and sometimes atoms so unstable that they decompose spontaneously, releasing more energy than that used to start this series of decompositions.

In artificial as well as in natural radioactive decomposition, energy is always delivered, and exact experiments have proved that the total weight of the fragments is smaller than that of the original nucleus. The loss of weight, i.e., of matter, and the simultaneous evolution of energy, allow the conclusion that matter has been converted into energy. The energy-equivalent of matter is extremely high. Whereas one kilogram of matter delivers 12 hp-hours when burned like coal, and 640,000 hp-hours when decomposed like radium, it would deliver 1,200,000,000,000,000 hp-hours when entirely converted into energy. At present we are able to convert only a tiny percentage of the original substance into energy. Nevertheless, the annihilation of even an infinitesimal amount of matter delivers quantities of energy as great as are otherwise available. For widespread exploitation of this source of energy, all we lack is a substance which is so cheap and amply accessible that the small percentage of hits does not matter, and which, through the bombardment of its nucleus, produces fragments so unstable that a large amount of energy is rapidly delivered. At present it is impossible to say how near we are to the practical use of atom disintegration, which may one day be the main source of energy.

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We have seen that there are several sources of energy and many means of transforming and storing it. But it may be said in general that nearly all our energy is derived from one source, from the sun, and that it is transformed and stored mainly by the two ancient, natural methods: physically, by utilizing the mechanical energy of the wind and the potential energy of raised water; and chemically, by utilizing the chemical energy of carbon compounds. There has been no great progress, and there is at present practically no artificial method. Grandfather saw the sun raise water, conducted the water over his mill wheel, and got motion; we do the same now in our big water power plants. Grandfather let the sun produce carbon compounds (wood, coal), filled them into his stove, and got heat, i.e., he regained the heat stored in summer; we still do the same. Grandfather let the sun produce carbon compounds (grass, oats), filled them into his horse, and got the motion of horse's legs; we fill the carbon compounds (coal, gasoline) into our motors and get the motion of wheels. In principle, there is no difference, although the new processes may be more convenient.

The difference between former times and the present is not in the method of obtaining energy but in that of distributing and transforming it. Grandfather could obtain energy only at the place and time where there was either moving (or movable) air or water, or where there were carbon compounds. Thanks to the invention of the dynamo, we have electricity, which can be used independently of places and times where there is motion of air or water or where there are deposits of carbon compounds. We have also got new means of transforming energy: we transform the motion of falling water into electricity and the latter at the place of consumption into motion, heat, light, radio waves; and we transform the chemical energy of carbon compounds not only into heat or animal motion but also into the motion of steam- and combustion engines. Because we make a better use of the old methods of gaining energy by better distribution and transformation, each of us now enjoys more energy than his grandfather did.

Nevertheless, our grandsons will not be satisfied with this. Probably they will make use of far more water power for producing electricity, using coal for this purpose only where there is not enough water power. They may use electricity for driving their cars or even their airplanes, if in the meantime they have found better means of storing this type of energy. At places where there is no wind, no raised water, no vegetation, and no connection with a power plant, as in the desert, we can foresee the direct use of sun radiation for human comfort, by means of an improved form of photocell, for instance. And if they should succeed in harnessing atom disintegration for practical use, they will obtain quantities of energy such as we have never known; then the danger may arise that they fight for the best raw material for disintegration, just as we fight for oil or a place in the sun.

How Many Calories Do You Need?

According to Dr. Hermann Schall's diet tables, the minimum requirement of a human being is one calory per kilogram per hour, i.e., if he weighs 70 kilograms, he needs $70 \times 24 = 1{,}680$ calories per day. The following additional calories are required for every hour of the following types of work:

Mental Work	7 to 8	Typewriting	16 to 40	Singing	11 to 56
Bookbinding	43 ,, 71	Sewing	31 ,, 88	Piano-playing	40 ,, 105
Shoemaking	80 ,, 115	Housework	87 ,, 174	Organ-playing	80 ,, 130
Sawing Wood	290 ,, 420	Laundrywork	230	Conducting	44 ,, 95